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REPORT NO. T21-88

**MASS-TO-SURFACE AREA RATIO IN
MILITARY PERSONNEL**

**US ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**

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**UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND**

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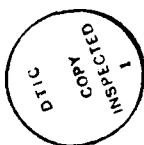
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→ in M/SA with age may be explained by an increase in percent body fat (%BF). %BF increased significantly in both males and females after age 24 ($p < .025$). (2) M/SA was statistically similar between ethnic groups in both males and females. However, black males had a lower %BF and a larger fat-free mass than males in other ethnic groups ($p < .001$). (3) For the first time, four equations are presented which allow an accurate calculation of M/SA ($r^2 = .99$) using only height and weight. The results of this investigation will be useful in analyzing data in future studies designed to determine if M/SA is in fact an index of heat tolerance.

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TECHNICAL REPORT NO. T21/88

MASS-TO-SURFACE AREA RATIO IN
MILITARY PERSONNEL

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Abstract

Mass-to-surface area ratio (M/SA) was calculated from the body weight and skin surface area of 1513 male and female U.S. Army personnel. It has been suggested that M/SA plays a role in thermoregulation, particularly in hot-humid environments, since both body weight and surface area affect the rate of body heat storage. The purpose of this investigation was to provide a data base to be used when interpreting M/SA data in future studies. The effects of gender, ethnic group, and age on the distribution of M/SA were examined, in addition to the relationship between M/SA and other physical characteristics. This report also describes the physical characteristics of individuals at the extremes of the M/SA distribution, who may have reduced heat dissipation capacity under certain conditions of heat and humidity. Important findings may be summarized as follows: (1) M/SA increased significantly in both males and females after age 24, and after age 29 in males ($p < .025$). Therefore, M/SA values should be compared with data in the appropriate age group. The increase in M/SA with age may be explained by an increase in percent body fat (%BF). %BF increased significantly in both males and females after age 24 ($p < .025$). (2) M/SA was statistically similar between ethnic groups in both males and females. However, black males had a lower %BF and a larger fat-free mass than males in other ethnic groups ($p < .001$). (3) For the first time, four equations are presented which allow an accurate calculation of M/SA ($r^2 = .99$) using only height and weight. The results of this investigation will be useful in analyzing data in future studies designed to determine if M/SA is in fact an index of heat tolerance.

INTRODUCTION

In 1984 the Exercise Physiology Division of USARIEM conducted a major study to develop recommendations for percentage of body fat standards to be used in the implementation of the U.S. Army weight control program (11). Body composition and physical fitness data were collected from 1194 male and 319 female active duty Army personnel. An attempt was made to collect data from a sample which would be representative of all U.S. Army soldiers, with respect to gender, age, and racial/ethnic group. The purpose of this report is to use this data base to examine an additional parameter, mass-to-surface area ratio (M/SA), and its significance in thermoregulation.

The Heat Research Division of USARIEM calculated M/SA from each subject's body mass and skin surface area. M/SA expresses body mass per square meter of skin surface area. Theories have been proposed to explain the relationship between M/SA , heat dissipation, and work efficiency under different environmental conditions (see Appendix 2). Some investigators (5,9,13,20,24,27,29) believe that M/SA is a definitive property in thermoregulation, since both body weight and surface area affect the rate of body heat storage.

Individuals with very high M/SA and very low M/SA may be susceptible to heat injury under certain environmental conditions. The calculation of M/SA thus provides a possible means of identifying such individuals. M/SA values reported in the literature should be interpreted with caution, however, because no large body of data exists which can be used as a reference standard for M/SA .

The purpose of this report is to provide a data base which offers a useful means to interpret M/SA values of subjects who are healthy, physically fit, and between the ages of 17 and 49 years. This report also explores the possibilities that M/SA is an index for screening heat intolerant persons, and that the

calculation of this value may be a practical way to estimate a soldier's risk of heat injury.

METHODS

After written informed consent was obtained, anthropomorphic and physical fitness data were collected from a cross-section of U.S. Army officers and enlisted personnel at Fort Hood, Texas and Carlisle Barracks, Pennsylvania. Although several types of measurements were made, only those applicable to the M/SA question were incorporated into the data base used by the Heat Research Division. These include height (H), mass (M), percent body fat (%BF), aerobic power, and 2-mile run time in the Army Physical Readiness Test (APRT), which was obtained from each subject's organizational files.

Body density and %BF were estimated using a portable hydrostatic weighing system developed by the Exercise Physiology Division (12). A Hewlett-Packard desktop computer sampled underwater weight every 10-15 seconds, calculating body density according to the formula of Buskirk (6) and %BF according to the formula of Siri (26).

Aerobic power was measured as maximal oxygen uptake ($\dot{V}O_{2\max}$) using a continuous incremental treadmill test adjusted for sex, age, and activity level. All subjects aged 17-34, and physically active subjects aged 35-39, ran to exhaustion as the treadmill grade increased 2.5% every 3 minutes (maximum of 15%). Treadmill speed was increased by 0.5 mph every 3 minutes from the initial speeds of 6 mph (males) and 5 mph (females). Inactive subjects aged 35-39, and all subjects aged 40 and older, underwent a modified U.S. Air Force School of Aerospace Medicine (USAFSAM) $\dot{V}O_{2\max}$ protocol (31). This test began at 3.3 mph and 0% grade; the treadmill grade increased 2.5% every 3 minutes to a maximum of 15%.

The test was then continued at 6 mph and 0% grade, and the grade increased 2.5% every 3 minutes.

DATA ANALYSIS

The data file was revised, after it was obtained by the Heat Research Division. Data for each subject were screened, to eliminate values which were obviously incorrect. Thirty-eight subjects were eliminated from the original data file (11) on the basis of inaccurate data. Five subjects (aged 50-54) were eliminated from the statistical data analysis due to the small size of this category. These deletions explain the differences between the data in this report and the original data in the report by Fitzgerald et al. (11).

To compare M/SA among sub-samples, subjects were categorized by sex, age, and race. Age categories were chosen which would be both physiologically meaningful and which would encompass an adequate sample size. The racial and ethnic categories in the original study by Fitzgerald et al (10) were those suggested by Wallman and Hogdon (30). Due to small sample size, ethnic groups other than "white" or "black" were combined for the purpose of analysis in this report into a category named "other". This category includes Hispanics, Alaskans/Native Americans, and Asians/Pacific Islanders. To ensure representative samples, any age or race category with less than 29 subjects was eliminated from the statistical data analysis.

Fat-free mass (FFM) and M/SA were calculated and incorporated into the data file. FFM is defined as body weight minus the weight of adipose tissue, as determined by techniques such as underwater weighing (7). SA was calculated according to the original formula of Du Bois and Du Bois (8).

The formula M/H^2 was used to compute body mass index (BMI), a predictor of body fatness (21). Summary statistics were calculated and histograms constructed for M/SA data in each gender, age, and racial category.

Departures from normality in the M/SA distributions were assessed via chi-square goodness of fit testing (32). Two-way analysis of variance (ANOVA) was used to determine significant differences between age and racial categories. The Student-Newman-Keuls post hoc analysis was used to test for significance between specific categories. Statistical analyses were performed by computer using original programs and BMDP Statistical Software (Los Angeles, CA.).

Means and confidence limits (± 2 S.D.) were computed for M/SA, H, and M in each age group and racial category. Larger age categories were used in the comparison of races, to ensure adequate sample size. Descriptive characteristics for all males and all females were examined in the following three groups: SMALL (subjects with M/SA smaller than -2 S.D. of the mean, or very small-bodied individuals), LARGE (subjects with M/SA larger than $+2$ S.D. of the mean, or very large-bodied individuals), and AVERAGE (subjects with M/SA within ± 2 S.D. of the mean).

Two linear regression prediction equations were computed, using the dependent variables of FFM and %BF, to test the assumption that FFM contributed more to the variability of M/SA. Finally, a step-wise multiple linear regression equation was computed using the dependent variables of H and M to predict M/SA. Data from all males and females, regardless of age and race, were used in these regression analyses.

RESULTS

Fig. 1 and Fig. 2 show the M/SA distribution for all males and all females, respectively. Females had a significantly smaller M/SA ($p < .001$), as expected, due to their tendency to be lighter and shorter than males. The mean M/SA for females was $36.5 \pm 2.4 \text{ kg/m}^2$; the mean M/SA for males was $39.8 \pm 2.9 \text{ kg/m}^2$.

Table 1 lists the mean M/SA and confidence limits (± 2 S.D.) in each age group. M/SA increased significantly with age in both males and females. Subjects under age 25 had a significantly lower M/SA than subjects in all other age groups; males aged 25-29 had a significantly lower M/SA than males aged 30 and older. This shift to the right in M/SA distribution with increasing age is illustrated in Fig. 3 (males) and Fig. 4 (females).

Table 2 lists the mean M/SA and confidence limits categorized by age and race, for males and females. M/SA was statistically similar between racial groups in both males (Fig. 5) and females (Fig. 6). However, black males had a lower %BF ($p < .001$) and a higher FFM ($p < .001$) than white or "other" males (not shown).

Chi-square analysis revealed that M/SA was not distributed normally in the following categories ($p < .001$): all males, white males, black males, males aged 17-24, and males aged 40-44. These distributions were positively skewed, and somewhat leptokurtic (having many values around the mean and "tails"). M/SA was distributed normally in all female categories.

Table 3 and Table 4 present descriptive characteristics of males and females in the following three groups: SMALL (subjects with M/SA smaller than -2 S.D. of the mean), LARGE (subjects with M/SA larger than $+2$ S.D. of the mean), and AVERAGE (subjects with M/SA between -2 S.D. and $+2$ S.D.). All three groups encompass a wide range of ages.

Figure 1

Frequency distribution of M/SA (kg/m^2):
Males

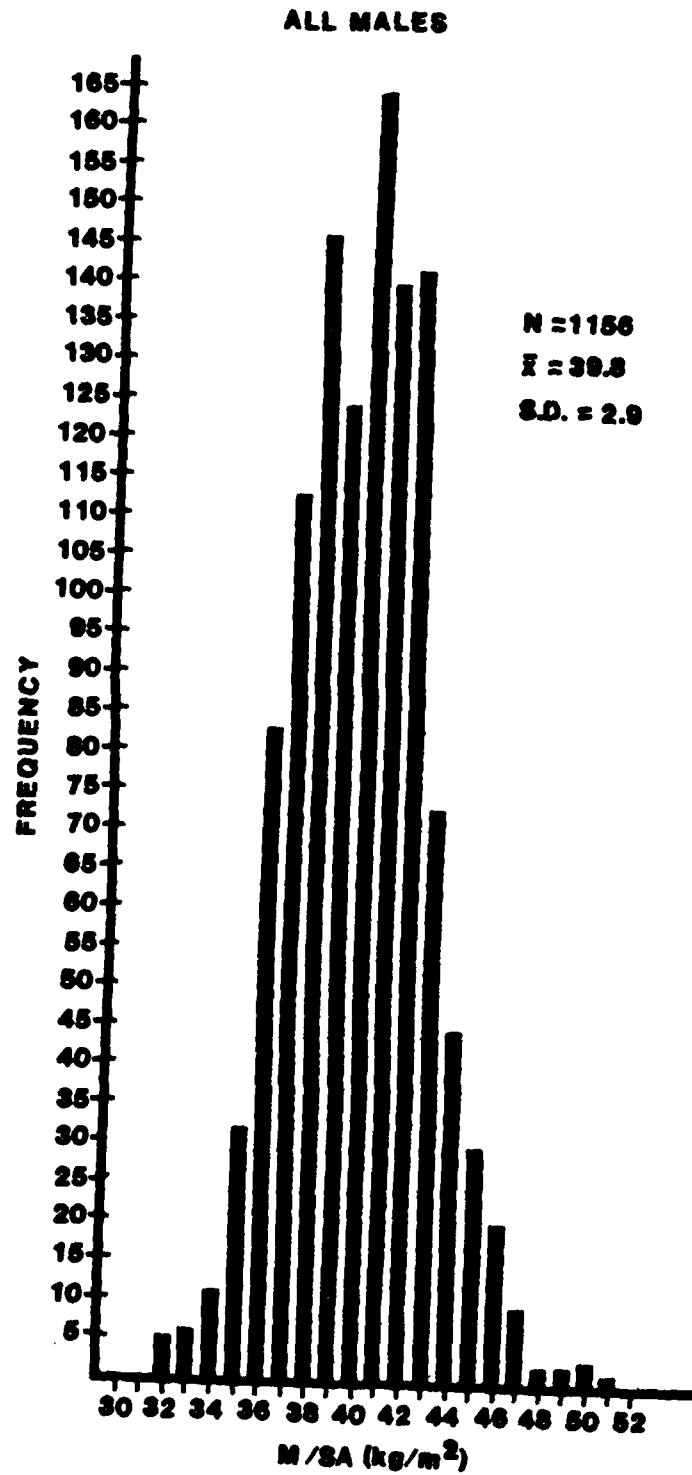


Figure 2

Frequency distribution of M/SA (kg/m^2):
Females

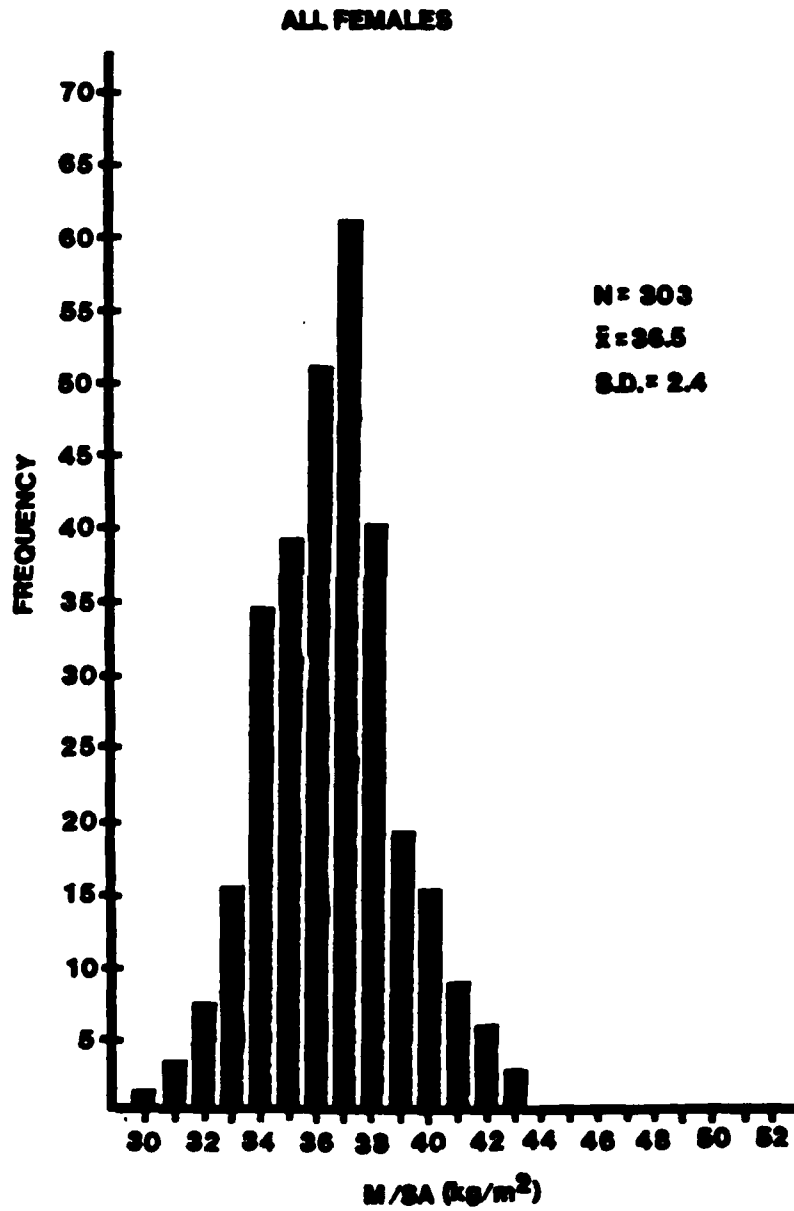


Table 1

M/SA (kg/m²) CATEGORIZED BY AGE (ALL INDIVIDUALS INCLUDED)

<u>SEX</u>	<u>AGE GROUP</u>	<u>N</u>	<u>-2 S.D.</u>	<u>-1 S.D.</u>	<u>MEAN</u>	<u>+1 S.D.</u>	<u>+2 S.D.</u>
M	* 17 - 24	387	33.5	36.1	38.7	41.4	44.0
M	+ 25 - 29	247	34.3	37.1	40.0	42.8	45.6
M	30 - 34	122	33.8	37.0	40.2	43.4	46.6
M	35 - 39	138	34.3	37.6	40.9	44.2	47.5
M	40 - 44	196	36.1	38.4	40.8	43.2	45.6
M	45 - 49	66	36.1	38.1	40.0	42.0	43.9
F	* 17 - 24	191	31.9	34.0	36.1	38.2	40.3
F	25 - 29	61	31.7	34.3	36.9	39.4	42.0
F	30 - 34	39	32.1	34.8	37.5	40.2	43.0

* significantly different from all other age groups (p<.025)

+ significantly different from the following age groups: 35-39, 40-44 (p<.025)

Table 2

M/SA (kg/m²) CATEGORIZED BY AGE AND RACE

<u>SEX</u>	<u>RACE</u>	<u>AGE GROUP</u>	<u>N</u>	<u>-2 S.D.</u>	<u>-1 S.D.</u>	<u>MEAN</u>	<u>+1 S.D.</u>	<u>+2 S.D.</u>
M	WHITE	17 - 25	255	33.6	36.2	38.9	41.5	44.1
M	WHITE	26 - 34	149	34.4	37.4	40.4	43.4	46.4
M	WHITE	35 - 39	76	34.4	37.7	41.0	44.3	47.5
M	WHITE	40 - 49	227	36.2	38.4	40.6	42.8	45.0
M	BLACK	17 - 25	116	34.0	36.5	38.9	41.4	43.9
M	BLACK	26 - 34	108	33.6	36.8	39.9	43.1	46.2
M	BLACK	35 - 39	31	34.4	37.7	40.9	44.1	47.3
M	OTHER *	17 - 25	57	32.4	35.4	38.3	41.3	44.2
M	OTHER *	26 - 34	71	33.9	36.9	39.9	42.9	45.9
M	OTHER *	35 - 39	31	33.6	37.1	40.6	44.1	47.6
F	WHITE	17 - 25	106	31.7	33.9	36.0	38.2	40.3
F	WHITE	26 - 34	42	31.3	34.3	37.4	40.5	43.5
F	BLACK	17 - 25	83	32.0	34.1	36.2	38.3	40.3
F	BLACK	26 - 34	29	33.2	35.3	37.4	39.5	41.6

* OTHER includes the following ethnic groups: Hispanic, Alaskan/Native American, Asian/Pacific Islander

Figure 3

Frequency distribution of M/SA (kg/m²) categorized by age:
Males

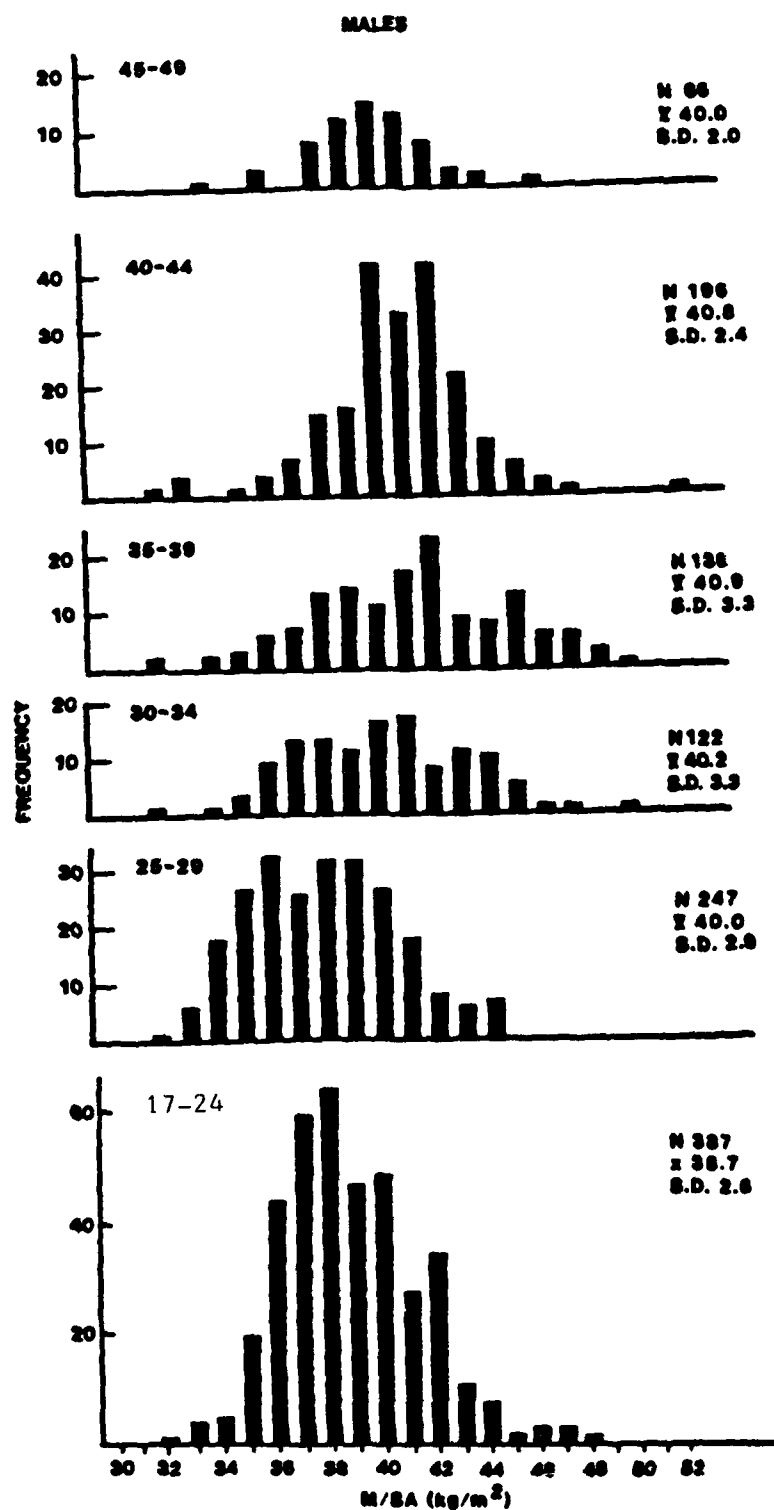


Figure 4

Frequency distribution of M/SA categorized by age:
Females

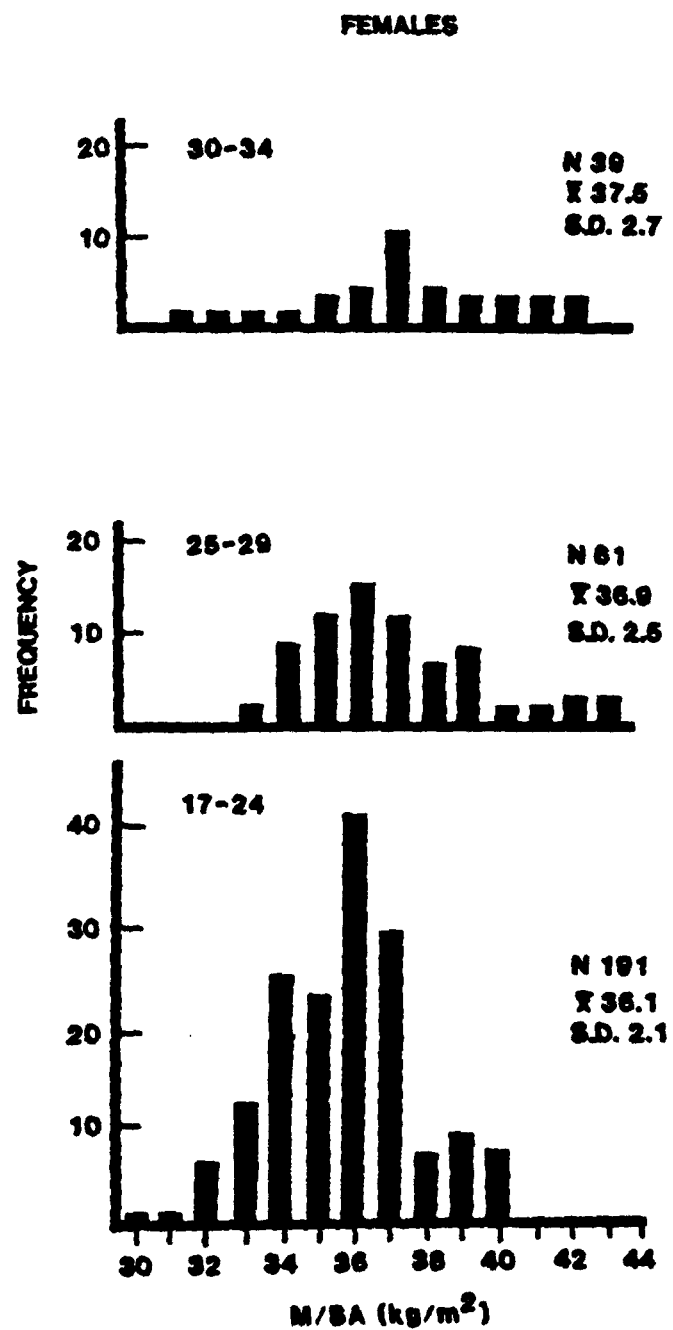


Figure 5

Frequency distribution of M/SA categorized by race:
Males

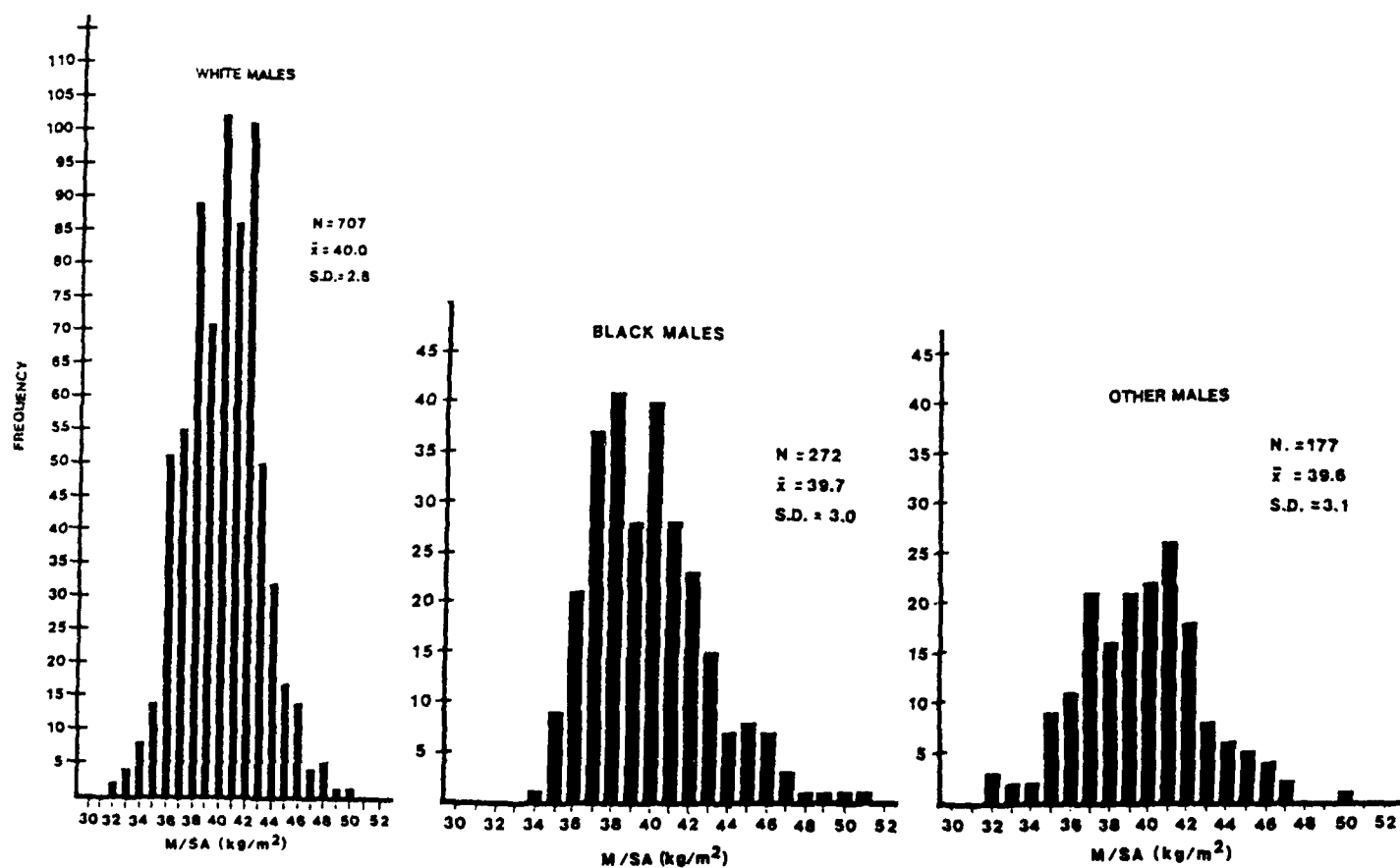


Figure 6

Frequency distribution of M/SA categorized by race:
Females

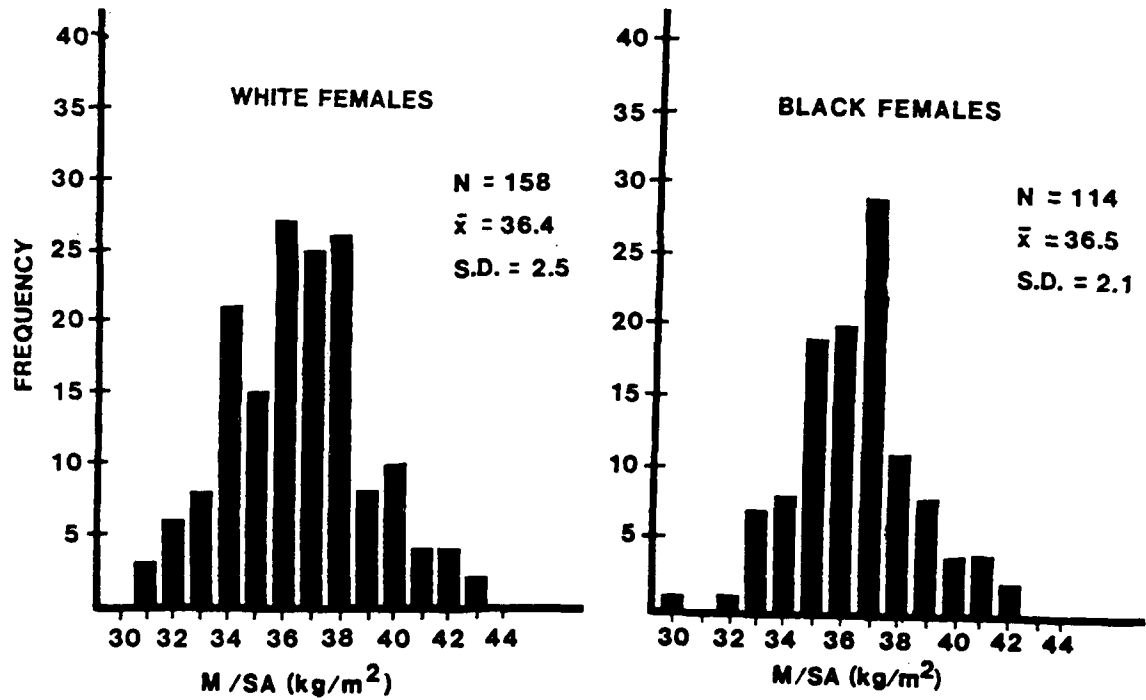


Table 3

**Comparison of descriptive characteristics:
SMALL, AVERAGE, LARGE Males**

Characteristic	SMALL (19 subjects)			Minimum	Maximum
	Mean	S.D.	S.E.		
Age	28.9	9.0	2.3	18.0	44.0
H (cm)	170.1	6.0	1.4	159.1	183.1
M (kg)	53.6	3.9	0.9	48.0	59.0
SA (m ²)	1.6	0.1	0.0	1.5	1.8
M/SA (kg/m ²)	33.2	0.8	0.2	31.7	34.2
BMI (kg/m ²)	18.1	0.6	0.2	17.4	18.0
%BF	16.2	5.5	1.3	8.0	29.0
FFM (kg)	44.9	4.7	1.1	36.0	52.5
$\dot{V}O_2$ max (ml/kg/min)	50.049	5.595	1.357	38.000	60.000
$\dot{V}O_2$ max (L/min)	2.688	0.472	0.017	2.048	5.568
2-mile (min)	14.53	2.11	0.37	12.18	18.00

Characteristic	AVERAGE (1112 subjects)			Minimum	Maximum
	Mean	S.D.	S.E.		
Age	30.4	9.0	0.3	18.0	54.0
H (cm)	175.1	6.9	0.2	155.4	195.9
M (kg)	76.3	9.8	0.3	51.0	104.0
SA (m ²)	1.9	0.1	0.0	1.5	2.3
M/SA (kg/m ²)	39.7	0.2	0.1	34.3	45.7
BMI (kg/m ²)	25.0	3.1	0.1	17.4	37.7
%BF	20.1	6.5	0.2	6.0	38.0
FFM (kg)	60.7	6.6	0.2	36.7	82.7
$\dot{V}O_2$ max (ml/kg/min)	47.912	6.018	0.222	31.000	66.000
$\dot{V}O_2$ max (L/min)	3.570	0.472	0.017	2.048	5.568
2-mile (min)	14.55	2.04	0.40	10.06	24.00

Characteristic	LARGE (34 subjects)			Minimum	Maximum
	Mean	S.D.	S.E.		
Age	31.7	7.5	1.2	20.0	53.0
H (cm)	179.4	6.9	1.2	168.8	195.9
M (kg)	106.8	8.8	1.5	93.0	126.0
SA (m ²)	2.3	0.1	0.0	2.0	2.5
M/SA (kg/m ²)	47.4	1.4	0.3	45.7	50.9
BMI (kg/m ²)	33.2	1.7	0.3	31.0	37.7
%BF	30.2	4.7	0.8	20.0	39.0
FFM (kg)	74.5	8.4	1.5	59.8	95.2
$\dot{V}O_2$ max (ml/kg/min)	38.360	2.548	0.510	33.000	43.000
$\dot{V}O_2$ max (L/min)	4.081	0.429	0.086	3.255	4.914
2-mile (min)	17.08	1.50	0.20	14.00	22.00

Legend

SMALL: subjects with M/SA smaller than -2 S.D. of the mean
 LARGE: subjects with M/SA larger than +2 S.D. of the mean
 AVERAGE: subjects with M/SA within ± 2 S.D. of the mean

Table 4

Comparison of descriptive characteristics:
SMALL, AVERAGE, LARGE Females

Characteristic	SMALL (8 subjects)			Minimum	Maximum
	Mean	S.D.	S.E.		
Age	25.0	7.0	2.0	18.0	40.0
H (cm)	159.9	2.6	0.9	156.5	163.3
M (kg)	45.0	1.5	0.5	43.0	47.0
SA (m ²)	1.4	0.3	0.0	1.4	1.5
M/SA (kg/m ²)	31.4	0.6	0.2	30.2	31.8
BMI (kg/m ²)	17.2	0.3	0.3	16.3	17.6
%BF	21.5	7.5	2.6	16.0	39.0
FFM (kg)	35.4	4.7	1.1	36.0	52.5
$\dot{V}O_2$ max (ml/kg/min)	41.000	5.329	2.176	38.000	49.000
$\dot{V}O_2$ max (L/min)	1.858	0.296	0.121	1.419	2.303
2-mile (min)	18.14	2.04	0.56	15.00	20.06

AVERAGE (286 subjects)					
Characteristic					
Age	24.0	5.0	0.3	18.0	54.0
H (cm)	162.4	6.3	0.4	145.3	179.2
M (kg)	59.6	6.9	0.4	44.0	81.0
SA (m ²)	1.6	0.1	0.0	1.4	2.0
M/SA (kg/m ²)	36.4	2.0	0.1	32.0	41.1
BMI (kg/m ²)	22.5	2.2	0.1	17.7	28.3
%BF	27.3	5.3	0.3	11.0	41.0
FFM (kg)	43.7	6.7	0.2	36.7	82.7
$\dot{V}O_2$ max (ml/kg/min)	39.420	4.345	0.275	28.000	53.000
$\dot{V}O_2$ max (L/min)	2.330	0.300	0.019	1.521	3.174
2-mile (min)	18.43	2.20	0.08	12.30	27.24

LARGE (9 subjects)					
Characteristic					
Age	28.0	3.0	1.0	20.0	53.0
H (cm)	165.0	10.8	3.6	150.7	182.7
M (kg)	78.9	7.9	2.6	70.0	93.0
SA (m ²)	1.9	0.2	0.1	1.7	2.2
M/SA (kg/m ²)	42.3	0.6	0.2	41.6	43.3
BMI (kg/m ²)	29.0	1.1	0.4	27.1	30.8
%BF	33.3	7.5	2.7	18.0	42.0
FFM (kg)	53.7	8.4	1.5	41.8	67.9
$\dot{V}O_2$ max (ml/kg/min)	34.125	3.563	1.260	29.000	40.000
$\dot{V}O_2$ max (L/min)	2.725	0.525	0.186	2.201	3.720
2-mile (min)	19.46	2.17	0.46	17.00	23.00

Legend

SMALL: subjects with M/SA smaller than -2 S.D. of the mean
 LARGE: subjects with M/SA larger than +2 S.D. of the mean
 AVERAGE: subjects with M/SA within ± 2 S.D. of the mean

It is noteworthy that LARGE males and females have a significantly lower $\dot{V}O_2$ max in ml/kg/min than SMALL and AVERAGE subjects, in spite of a significantly higher $\dot{V}O_2$ max in L/min. It is also interesting that %BF increases dramatically in LARGE males.

The relationship between M/SA using both FFM and %BF are shown in Fig. 7 (males) and Fig. 8 (females). The linear regression equation to predict M/SA using FFM accounted for 49% of the variability in males (Eq. 1) and 42% of the variability in females (Eq. 2). The linear regression equation to predict M/SA using %BF accounted for 37% of the variability in both males (Eq. 3) and females (Eq. 4). It is clear from these graphs that an individual with a relatively small M/SA can have a large %BF, and vice versa, particularly in males.

The multiple linear regression equation to predict M/SA accounted for 99% of the variability by using H and M as independent variables, and was significant at the $p < .001$ level. This equation took the form shown below for males (Eq. 5 and Eq. 6) and females (Eq. 7 and Eq. 8). M/SA can now be calculated from H and M, and determination of SA from equations or tables is unnecessary.

Males

$$Y \text{ (M/SA in kg/m}^2\text{)} = 45.401 + (0.294 * M \text{ in kg}) - (0.161 * H \text{ in cm}) \quad (\text{Eq. 5})$$

$$Y \text{ (M/SA in lb/yd}^2\text{)} = 83.892 + (0.246 * M \text{ in lb}) - (0.754 * H \text{ in in}) \quad (\text{Eq. 6})$$

Females

$$Y \text{ (M/SA in kg/m}^2\text{)} = 42.333 + (0.346 * M \text{ in kg}) - (0.164 * H \text{ in cm}) \quad (\text{Eq. 7})$$

$$Y \text{ (M/SA in lb/yd}^2\text{)} = 78.222 + (0.290 * M \text{ in lb}) - (0.769 * H \text{ in in}) \quad (\text{Eq. 8})$$

DISCUSSION

This report analyzes M/SA data for a representative sample of U.S. Army personnel by gender, age, and race. This data base can be used as a reference source when comparing M/SA values in future studies, particularly those investigating heat intolerant persons.

Figure 7

Relationship between FFM (kg) and M/SA (kg/m²)

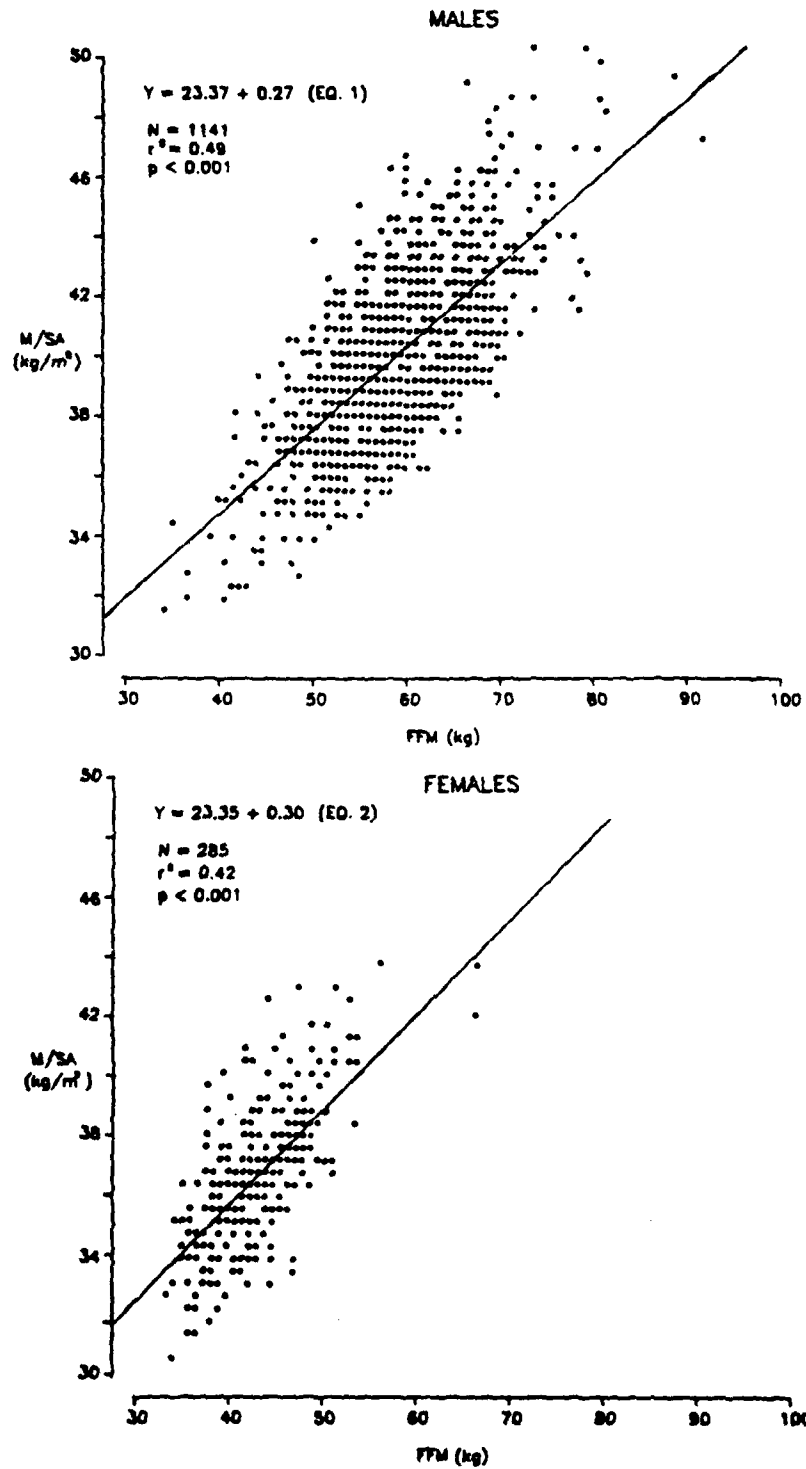
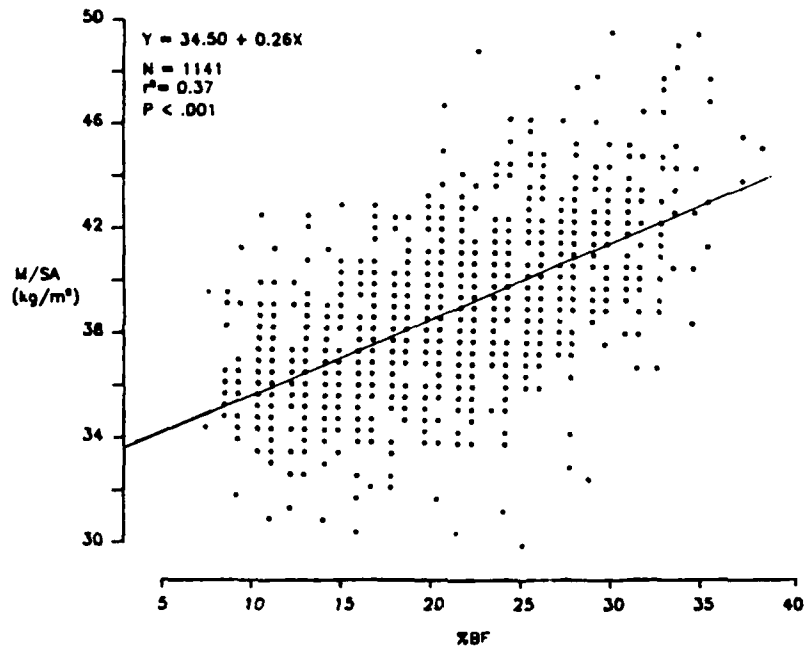


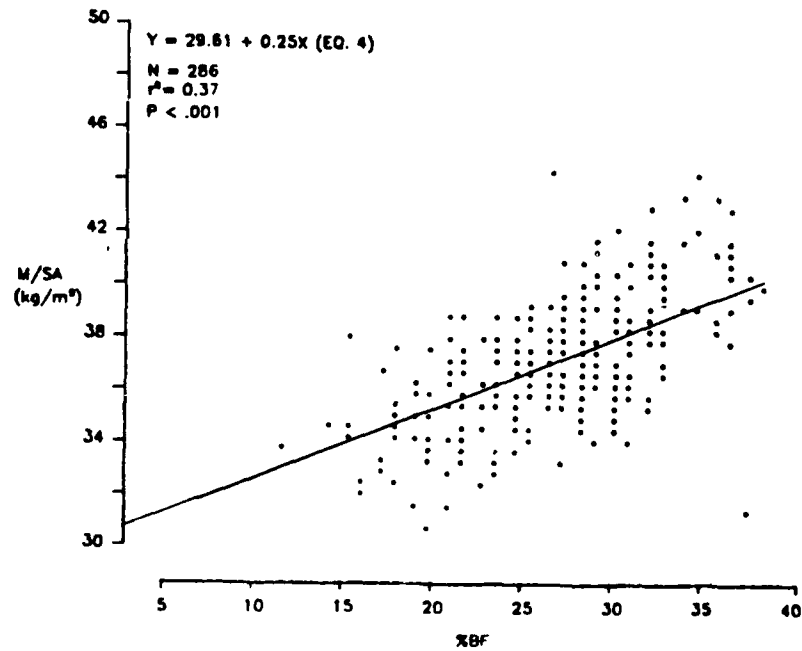
Figure 8

Relationship between %BF and M/SA (kg/m²)

MALES



FEMALES



M/SA values should be compared to data in the appropriate age group, since M/SA increases significantly with age. A large M/SA which is normal for a 40 year old male may be atypical for a 17 year old male. The increase in M/SA after age 25, in both males and females, can be explained by an increase in body fat and decrease in muscle mass with age. Males and females under age 25 were found to have significantly lower percent body fat than all other age groups (see Table 6).

Departures from normality in the M/SA distributions were not unexpected. The categories of all males, white males, black males, and 17-24 year old males represent very diverse groups of individuals. It is reasonable to assume that very large males are more prevalent than very small males in the military; this would account for the positively skewed distributions. In addition, one would expect to find a concentration of M/SA values around the mean, since military personnel must meet prescribed standards of weight and percent body fat.

Descriptive characteristics of subjects with M/SA at the "very small" and "very large" extremes were examined (Table 3 and Table 4) since these individuals may have an increased risk of hyperthermia. Although a large M/SA is most often associated with heat intolerance, very small individuals may also be susceptible to heat injury under certain conditions (see Appendix 2). It is significant that LARGE subjects have a lower $\dot{V}O_2$ max (in ml/kg/min), since a low maximal aerobic capacity has been linked to heat/exercise intolerance (26). It is also notable that LARGE subjects are significantly older than SMALL subjects; however, the effect of age on heat tolerance is negligible when subjects are matched for $\dot{V}O_2$ max (18).

The age categories used in this report are arbitrary and are used for the purpose of trend analysis. The groups are general categories and not precise cut-off points. It must also be kept in mind that since military personnel must adhere to standards of physical fitness, they will tend to weigh less and be more fit than their civilian counterparts. The data base contained in this report is applicable to soldiers and other physically active individuals, but may not be wholly applicable to the population at large.

CONCLUSION

The information presented in this report may be applied to athletic, industrial, and military situations. For the first time, four equations are presented which allow a streamlined, yet accurate, calculation of M/SA from H and M . The calculation of M/SA is a simple and informative screening procedure to identify those individuals who lie at the extremes of the M/SA distribution. This screening may be important when selecting individuals for certain tasks which involve hot environments, impermeable clothing, and strenuous exercise (see Appendix 2). Because the validity of predicting risk of heat intolerance from M/SA is still theoretical, factors such as age, health, cardio-respiratory fitness, and heat acclimation status cannot be overlooked.

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Appendix 1

Selected Descriptive Characteristics

Table 5
Descriptive characteristics of subjects

MALES

<u>Characteristic</u>	<u>N</u>	<u>Mean</u>	<u>S.D.</u>	<u>S.E.</u>	<u>Minimum</u>	<u>Maximum</u>
Age	1170	30.2	8.8	0.3	17.0	54.0
H (cm)	1165	175.1	6.9	0.2	155.4	195.9
M (kg)	1165	76.8	11.3	0.3	48.0	126.0
SA (m ²)	1165	1.9	0.2	0.0	1.5	2.5
M/SA (kg/m ²)	1165	39.8	2.9	0.1	31.7	50.9
BMI (kg/m ²)	1165	25.0	3.1	0.1	17.4	37.7
%BF	1153	20.3	6.7	0.2	6.0	39.0
FFM (kg)	1153	60.8	7.4	0.2	36.0	95.2
VO ₂ max (ml/kg/min)	780	47.644	6.170	0.221	31.000	66.000
VO ₂ max (L/min)	780	3.566	0.494	0.018	1.900	5.568
2-mile (min)	1046	14.58	2.04	0.04	10.06	24.00

FEMALES

<u>Characteristic</u>	<u>N</u>	<u>Mean</u>	<u>S.D.</u>	<u>S.E.</u>	<u>Minimum</u>	<u>Maximum</u>
Age	305	24.0	5.0	0.3	18.0	40.0
H (cm)	303	162.4	6.4	0.4	145.3	182.7
M (kg)	303	59.9	8.0	0.5	43.0	93.0
SA (m ²)	303	1.6	0.1	0.0	1.4	2.15
M/SA (kg/m ²)	303	36.5	2.4	0.1	30.2	43.3
BMI (kg/m ²)	303	22.7	2.5	0.1	16.3	30.8
%BF	289	27.3	5.6	0.3	11.0	42.0
FFM (kg)	289	43.3	5.0	0.3	26.2	67.9
VO ₂ max (ml/kg/min)	265	39.257	4.469	0.265	28.000	53.000
VO ₂ max (L/min)	265	2.331	0.322	0.020	1.419	3.270
2-mile (min)	289	17.48	2.22	0.08	12.50	27.40

Table 6

Descriptive characteristics of subjects categorized by age
Mean \pm S.D.

MALES

<u>Age</u>	<u>H (cm)</u>	<u>M (kg)</u>	<u>SA (m²)</u>	<u>BMI (kg/m²)</u>	<u>%BF</u>	<u>FFM (kg)</u>	<u>$\dot{V}O_2$ max (ml/g/min)</u>
17-24	174.7 \pm 6.4	72.8 \pm 9.9	1.9 \pm 0.1	22.9 \pm 2.8	16.4 \pm 5.7	60.5 \pm 6.9	50.994 \pm 4.969
25-29	174.2 \pm 7.1	76.8 * \pm 11.6	1.9 \pm 0.2	25.3 * \pm 3.1	20.0 * \pm 6.5	61.1 \pm 8.0	47.304 * \pm 5.624
30-34	173.8 \pm 6.8	77.3 \pm 12.7	1.9 \pm 0.2	25.5 \pm 3.5	21.7 * \pm 6.4	60.2 \pm 7.7	45.130 * \pm 5.4000
35-39	174.4 \pm 7.2	80.0 \pm 12.7	1.9 \pm 0.2	26.2 \pm 3.6	24.1 * \pm 6.4	60.4 \pm 8.5	42.657 * \pm 4.936
40-44	177.8 * \pm 6.9	81.6 \pm 10.0	2.0 * \pm 0.1	25.7 \pm 2.5	24.0 \pm 5.0	61.6 \pm 7.0	39.160 * \pm 3.727
45-49	177.4 \pm 5.9	78.5 \pm 8.1	2.0 \pm 0.1	24.9 \pm 2.1	23.4 \pm 4.9	60.2 \pm 5.4	insufficient data

FEMALES

<u>Age</u>	<u>H (cm)</u>	<u>M (kg)</u>	<u>SA (m²)</u>	<u>BMI (kg/m²)</u>	<u>%BF</u>	<u>FFM (kg)</u>	<u>$\dot{V}O_2$ max (ml/kg/min)</u>
17-24	161.1 \pm 6.2	58.6 \pm 6.9	1.6 \pm 0.1	22.3 \pm 2.3	26.2 \pm 5.3	43.2 \pm 4.3	40.066 \pm 4.084
25-29	162.6 \pm 7.1	61.4 * \pm 9.3	1.7 * \pm 0.1	23.2 * \pm 2.6	28.2 * \pm 5.0	43.8 \pm 6.5	38.438 * \pm 4.465
30-34	163.9 \pm 6.6	64.2 * \pm 9.1	1.7 * \pm 0.1	23.7 * \pm 3.2	30.5 \pm 6.8	44.4 \pm 5.6	37.000 * \pm 5.617

* significantly different from age group above it ($p < .025$)

Table 7

HEIGHT (cm) CATEGORIZED BY AGE (ALL INDIVIDUALS INCLUDED)

<u>SEX</u>	<u>AGE GROUP</u>	<u>N</u>	<u>-2 S.D.</u>	<u>-1 S.D.</u>	<u>MEAN</u>	<u>+1 S.D.</u>	<u>+2 S.D.</u>
M	17 - 24	387	161.8	168.3	174.7	181.1	187.6
M	25 - 29	247	159.9	167.0	174.2	181.3	188.5
M	30 - 34	122	159.5	166.7	173.8	180.6	187.4
M	35 - 39	138	160.0	167.2	174.4	181.6	188.8
M	40 - 44	196	164.0	170.9	177.8	184.7	191.6
M	45 - 49	66	165.6	171.5	177.4	183.3	189.2
F	17 - 24	191	149.7	155.9	162.1	168.3	174.5
F	25 - 29	61	148.4	155.5	162.6	169.7	176.8
F	30 - 34	39	150.7	157.3	163.9	170.5	177.1

Table 8

HEIGHT (cm) CATEGORIZED BY AGE AND RACE

SEX	RACE	AGE GROUP	N	-2 S.D.	-1 S.D.	MEAN	+1 S.D.	+2 S.D.
M	WHITE	17 - 25	255	162.1	168.6	175.1	181.6	188.1
M	WHITE	26 - 34	149	161.8	168.9	176.0	183.1	190.2
M	WHITE	35 - 39	76	161.1	168.2	175.3	182.4	189.5
M	WHITE	40 - 49	227	166.3	172.4	178.5	184.6	190.7
M	BLACK	17 - 25	116	161.9	168.1	174.3	180.5	186.7
M	BLACK	26 - 34	108	161.6	167.9	174.2	180.5	186.8
M	BLACK	35 - 39	31	163.5	170.2	176.9	183.6	190.3
M	OTHER *	17 - 25	57	158.8	165.5	172.2	178.9	185.6
M	OTHER *	26 - 34	71	157.5	164.0	170.5	177.0	183.5
M	OTHER *	35 - 39	31	158.4	164.1	169.8	175.5	181.2
F	WHITE	17 - 25	106	150.7	156.8	162.9	169.0	175.1
F	WHITE	26 - 34	42	149.1	156.6	164.1	171.6	179.1
F	BLACK	17 - 25	83	149.5	155.6	161.7	167.8	173.9
F	BLACK	26 - 34	29	150.9	157.7	164.5	171.3	178.1

* OTHER includes the following ethnic groups: Hispanic, Alaskan/Native American, Asian/Pacific Islander

Table 9.

MASS (kg) CATEGORIZED BY AGE (ALL INDIVIDUALS INCLUDED)

<u>SEX</u>	<u>AGE GROUP</u>	<u>N</u>	<u>-2 S.D.</u>	<u>-1 S.D.</u>	<u>MEAN</u>	<u>+1 S.D.</u>	<u>+2 S.D.</u>
M	17 - 24	387	53.1	62.9	72.8	82.7	92.5
M	25 - 29	247	53.7	65.3	76.8	88.5	100.1
M	30 - 34	122	51.9	64.6	77.3	89.9	102.6
M	35 - 39	138	54.5	67.3	80.0	92.7	105.5
M	40 - 44	196	61.6	71.6	81.6	91.5	101.5
M	45 - 49	66	62.4	70.0	78.5	86.5	94.6
F	17 - 24	191	44.7	51.7	58.6	65.5	72.4
F	25 - 29	61	42.8	52.1	61.4	70.7	80.0
F	30 - 34	39	45.9	55.0	64.2	73.3	82.5

Table 10

MASS (kg) CATEGORIZED BY AGE AND RACE

<u>SEX</u>	<u>RACE</u>	<u>AGE GROUP</u>	<u>N</u>	<u>-2 S.D.</u>	<u>-1 S.D.</u>	<u>MEAN</u>	<u>+1 S.D.</u>	<u>+2 S.D.</u>
M	WHITE	17 - 25	255	54.1	63.7	73.3	82.9	92.5
M	WHITE	26 - 34	149	54.6	66.9	79.2	91.5	103.8
M	WHITE	35 - 39	76	55.1	68.0	80.9	93.8	106.7
M	WHITE	40 - 49	227	63.1	72.1	81.1	90.1	99.1
M	BLACK	17 - 25	116	54.1	63.7	73.3	82.9	92.5
M	BLACK	26 - 34	108	52.9	64.7	76.5	83.8	100.1
M	BLACK	35 - 39	31	56.2	68.8	81.4	94.0	106.6
M	OTHER *	17 - 25	57	32.4	35.4	38.3	41.3	44.2
M	OTHER *	26 - 34	71	33.9	36.9	39.9	42.9	45.9
M	OTHER *	35 - 39	31	33.6	37.1	40.6	44.1	47.6
F	WHITE	17 - 25	106	31.7	33.9	36.0	38.2	40.3
F	WHITE	26 - 34	42	31.3	34.3	37.4	40.5	43.5
F	BLACK	17 - 25	83	32.0	34.1	36.2	38.3	40.3
F	BLACK	26 - 34	29	33.2	35.3	37.4	39.5	41.6

* OTHER includes the following ethnic groups: Hispanic, Alaskan/Native American, Asian/Pacific Islander

Appendix 2

Theoretical relationship between M/SA and heat tolerance

It has been stated that the intra-individual relationship between mass and surface area determines success or failure to thermoregulate (4, RR Gonzalez, personal communication). While M/SA no doubt plays some role in heat tolerance, it is unlikely that body composition alone determines heat tolerance. Several factors are involved in the physiological response to heat, such as age, health, nutrition, body water or intracellular competence, cardio-respiratory fitness, and heat acclimation status. The proposed relationship between M/SA and heat tolerance is discussed in this appendix.

The body dissipates heat to the environment primarily through radiation and convection when ambient temperature is lower than skin temperature, or when dew point temperature is less than skin temperature (lower than 36° C, or hot-humid heat). Heat is gained from the environment in the same way when ambient temperature is greater than skin temperature (greater than 36° C, or hot-dry heat). However, evaporation of sweat is the most effective means of heat dissipation in a hot-dry environment.

A small M/SA is theoretically an asset in a hot-humid environment, because there is a greater rate of heat transfer from the skin to the environment through radiation and convection. Heat loss through convection in water immersion has been described as being directly proportional to SA and inversely proportional to M (13). However, a very small individual is at a disadvantage in a hot-dry environment, since he has less skin surface area available for evaporation of sweat (27).

In contrast, a large individual theoretically stores more heat and has a greater risk of hyperthermia in a hot-humid environment. However, he may have

an advantage in dry heat when ambient temperature is substantially greater than skin temperature, and sweat rate is a limiting factor.

Females are theoretically more tolerant of humid heat and less tolerant of dry heat, due to their smaller M/SA and lower sweat rate than males albeit greater number of sweat glands per cm² of skin (14). A small M/SA was found to be an advantage during intense exercise in cool conditions, in one study (5); female body size had little influence on thermal strain under hot-dry conditions in another investigation (10). In addition, women have a lower total body water, and substantial sweating could lead to a greater percent dehydration than males, and greater cardiovascular instability. Females have been reported to have lower heart rates and rectal temperatures than males when exercising in hot, humid environments (1,19,23). When matched for M/SA, however, there are no significant differences in heart rate or rectal temperature between the sexes (23).

Individuals with very high or low M/SA may be more likely to be heat intolerant (see Tables 3 and 4). Miners who weigh less than 50 kg have been reported to be less heat tolerant than their heavier counterparts (27), while football linemen with very high M/SA have been reported to be at significant risk of hyperthermia, particularly in humid environments. Football lineman exhibit lower heat tolerance than backs, even when the two groups are matched for $\dot{V}O_2\text{max}$ (29).

Israeli investigators have reported that a large M/SA is the physical characteristic which best distinguished heat intolerant males and former heat stroke patients from normal individuals (9), when compared to age, M, H, SA, $\dot{V}O_2\text{max}$, and muscular work efficiency. In addition, heat injury patients with

large M/SA were found to be more likely to die of heatstroke, when compared to heatstroke victims with smaller M/SA (22).

A large M/SA suggests that either fat-free tissue or %BF are potentiated with respect to body skin surface area. FFM has been found to be highly correlated with heat strain (sweat loss, rectal temperature, heart rate) in men acclimatizing to dry heat (3). It has also been reported that a large muscle mass predisposes athletes to heat injury, since a large percentage of body water can be lost during intense exercise in a hot environment (17).

Individuals with a large percent body fat have a lower heat flux per unit skin surface than leaner individuals, and may be less tolerant to high ambient temperatures under some conditions. Obese individuals often have cardiopulmonary systems which are functionally inferior (5), exercise at a greater percentage of VO_2max , and have a lower work efficiency. Obese men (15) and women (5) have shown greater physiological strain to exercise-heat stress than their leaner counterparts. Obese men have been observed to store heat more rapidly than normal men after the cessation of exercise (16).

Obese individuals, or individuals with large M/SA, may be handicapped by a higher heat strain than their leaner or smaller counterparts, when performing tasks which displace the center of gravity (and are therefore weight-dependent) (4). Factors such as body size, type of work, and the temperature and humidity of the environment should be considered when selecting individuals for such athletic, industrial, and military activities (20).

An inverse relationship has been found between %BF and metabolic rate in cold immersion studies (28). When this relationship is incorporated into equations to predict core and skin temperature response during cold water immersion,

the validity of these models is improved. We recognize the possible application of the data base presented in this report in future prediction modelling studies.

The relationship between M/SA ratio and heat tolerance apparently does not hold true in all environments. In one investigation, a computer-simulated model (2) of the relationship between body composition and hyperthermia indicated that heat storage increased as mass-to-surface area ratio increased, but only in environments ranging from 30° C, 80% relative humidity (rh) to 45° C, 80% rh. It has also been reported that M/SA is not highly correlated with rectal temperature during exercise in a hot-dry environment (24,25). M/SA evidently becomes more important to heat tolerance under severe conditions of heat and humidity with high workloads, and less important under moderate environmental conditions with light workloads.

In conclusion, it is probable that very large and very small, thin individuals should take precautions under extreme conditions of heat and exercise. While heat intolerance is not a purely biophysical problem, body composition plays a definitive role in heat exchange under hot-humid conditions. Future research will, no doubt, shed more light on the significance of this role.

Disclaimers

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as official Department of the Army position, policy, or decision, unless so designated by other official documentation.

Human subjects participated in these studies after giving their informed voluntary consent. Investigators adhered to AR 70-25 for use of volunteers in research.

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